Indicator: Terrestrial Plant Growth Index (145)

Primary productivity (the amount of solar energy captured by plants through photosynthesis) is a key indicator of ecosystem function (NRC, 2000; EPA, 2002). Generally, ecosystems will maximize their primary productivity through adaptation (Odum, 1971), so primary productivity can increase under favorable conditions (e.g., increased nutrients or rainfall) or decrease under unfavorable conditions (e.g., plant stress caused by toxic substances or disease). Changes in primary productivity can result in changes in the way ecosystems function, in the yield of crops or timber, or in the animal species that live in the ecosystems. Over a sufficiently long period, trends in Normalized Difference Vegetation Index (NDVI) could be an important indicator of increasing or decreasing plant growth resulting from changing climate, UV-B exposure, air pollution, or other stressors.

Gross primary productivity is related to the standing crop of the photosynthetic pigment chlorophyll and can be thought of as an index of plant growth. The Terrestrial Plant Growth Index indicator developed by The Heinz Center (2003) is based on the NDVI, which measures the amount of chlorophyll using satellite data (Reed and Yang, 1997). Although the standing crop of chlorophyll is not identical to primary productivity, NDVI also correlates well with net uptake of carbon dioxide and plant biomass production (Birky, 2001). The index shows, for any given year, whether plant growth for an ecosystem type was above or below the 13-year average (1989-2002).

This indicator is based on data collected by the Advanced Very High Radiation Radiometer (AVHRR) aboard NOAA's polar orbiting satellites between 1989 and 2002 (except for 1994 when the satellite failed). Each 1.1 km^2 pixel is sampled twice each day. Because the relationship between NDVI and absorbed, photosynthetically-active radiation varies by cover type, the growing season accumulated NDVI was calculated separately for the forest, farmland, and grassland/shrubland areas in each county of the conterminous 48 states. The NDVI was calculated at 2-week intervals and summed throughout the growing season using only values that exceeded non-growing-season background. The values in each county segment for each year then were normalized to the corresponding 13-year average for that county segment to produce a plant growth index for which a value of 1.0 equals the long-term average (a value of 1.5 represents 1.5 times the long-term average). The system-specific plant growth indices are the area-weighted averages of the segments contained within the system. The calculation algorithm and the resulting data for this indicator were updated in the 2003 Annual Update of *The State of the Nation's Ecosystems* (The Heinz Center, 2003).

What the Data Show

No overall trend in plant growth is observed from 1989 through 2002 for any of the land cover types studied, although year-to-year measurements can fluctuate by up to 40 percent of the 13-year average (Figure 145-1). The similarity in year-to-year variation among systems (e.g., above-average growth in 1993 and below-average growth in 1996) is striking. The reason for these trends is not clear (The Heinz Center, 2003).

Indicator Limitations

- In 2000, the NOAA satellite drifted to a new orbit; as a result, U.S. NDVI data began to reflect measurements made in late afternoon rather than midday. The effect of this drift on plant growth index is not fully known. However, because the index is accumulated from the beginning of the growing season—a point that is identified each year from the inherent seasonal patterns in the NDVI data—scientists at the EROS Data Center believe the 2000 estimates are comparable to those of previous years.
- Data for 1994 are unavailable because of satellite failure.

- Alaska and Hawaii are not included in this analysis.

Data Source

The data source for this indicator was The State of the Nation's Ecosystems, The Heinz Center, 2003 Annual Update, using data collected by the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer. Data on accumulated NDVI and analysis of those data are from the USGS Earth Resources Observations Systems (EROS) Data Center, Sioux Falls, South Dakota (http://edc.usgs.gov/products/landcover/ndvi.html).

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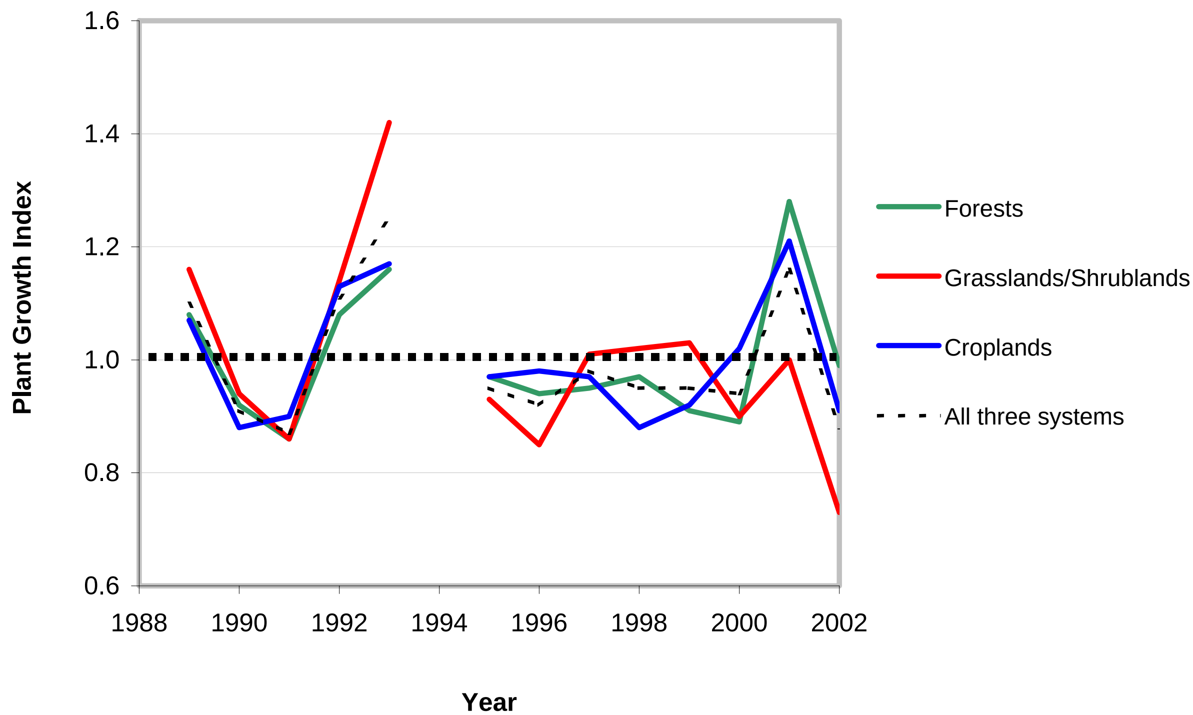
Graphics

Figure 145-1. Terrestrial Plant Growth Index



Source: The Heinz Center. The State of the Nation's Ecosystems. 2002. Online update 2003.
Data from the U.S. Geological Survey; Multi-Resolution Land Characterization Consortium
Coverage: lower 48 states

R.O.E. Indicator QA/QC

Data Set Name: TERRESTRIAL PLANT GROWTH INDEX
Indicator Number: 145 (89666)
Data Set Source: National Oceanic and Atmospheric Administration (NOAA)
Data Collection Date: regular: 1989 - 2002
Data Collection Frequency: daily
Data Set Description: Terrestrial Plant Growth Index
Primary ROE Question: What are the trends in the diversity and biological balance of the Nation's ecological systems?

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

The Terrestrial Plant Growth Index is based on the Normalized Difference Vegetation Index (NDVI), which measures chlorophyll using satellite data. USGS collects the raw data to support this indicator using the Advanced Very High Radiation Radiometer (AVHRR) aboard NOAA's polar-orbiting satellites. Currently, AVHRR data is available for the years 1989 to 2002 (except 1994, when a satellite failure prevented data collection). This sensor measures reflection/absorption of light; in this case, it measures the "greenness" of the vegetation below. Greenness relates to the amount of chlorophyll present; thus, this indicator represents a proxy for productive capacity. The raw data are not available to the public, as USGS performs several analytical steps before the data can be used for comparisons or indicators (see T1Q3). The Heinz Center (2003) reports that measurements are made in the visible wavelengths (0.58 to 0.68 meters) and near-infrared wavelengths (0.725   1.1 meters), corresponding with AVHRR channels 1 and 2. USGS documents these methods at http://edc.usgs.gov/greenness/whatndvi.html, with a list of supporting references at http://edc.usgs.gov/greenness/refs.html. USGS describes the NDVI concept with additional graphics and detail at http://edc.usgs.gov/greenness/helppage.html; this page also contains several links to information about NOAA   s satellites. In addition to satellite data on sunlight absorption, this indicator also requires information on land cover type in order to create separate growth indices for each of the major types of vegetative land cover in the United States (forest, grassland/shrubland, farmland). Land cover data come from the National Land Cover Dataset (NLCD), compiled in the 1990s by a consortium of government agencies (USGS, EPA, USDA Forest Service). The Heinz Center (2003 update) documents this classification process briefly (http://www.heinzctr.org/ecosystems/national_technotes/natl_extent.shtml); a more detailed discussion can be found in Vogelmann et al., 1998 and 2001: Vogelmann, J.E., T.L. Sohl, P.V. Campbell, and D.M. Shaw. 1998. Regional land cover characterization using LANDSAT Thematic Mapper data and ancillary data sources. Environmental Monitoring and Assessments 51: 415   428. Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, and N. van Driel. 2001. Completion of the 1990s national land cover data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering & Remote Sensing 67:650   662.

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

Neither the Heinz Center nor the government agencies responsible for data collection explicitly discusses the design of the raw data collection process. The Heinz Center reports that measurements are made twice a day, and that each measurement pixel corresponds with a mapping area of about 1.1 square kilometers (km) a relatively high resolution on a national scale.

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

To derive this indicator, USGS processed the raw data through several layers of analysis:

(1) USGS converted the raw data into a Normalized Difference Vegetation Index (NDVI). First, USGS combined information from two AVHRR sensor channels into one raw NDVI figure for each data point, as described at http://edc.usgs.gov/greenness/whatndvi.html. Because clouds, atmospheric perturbations, and variable illumination or viewing geometry can all contaminate raw data, USGS employs a smoothing algorithm to reduce the impact of such extraneous factors. To smooth the data, USGS groups the data into 2-week intervals, performs a series of least-squares regressions around each data point, averages the regression values, and then interpolates between points to generate a continuous curve. USGS also incorporates a factor that weights NDVI in favor of peaks rather than minima, since contamination typically causes lower-than-expected values of NDVI. USGS's website discusses this process briefly (http://edc2.usgs.gov/phenological/methods.html#methodsTS); a more in-depth discussion can be found in: Swets, D.L., B.C. Reed, J.R. Rowland, S.E. Marko, 1999. A weighted least-squares approach to temporal smoothing of NDVI. In 1999 ASPRS Annual Conference, From Image to Information, Portland, Oregon, May 17-21, 1999, Proceedings: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, CD-ROM, 1 disc.

The Heinz Report's 2003 web update describes an additional smoothing algorithm employed during a recent revision of the data set (http://www.heinzctr.org/ecosystems/national_technotes/natl_plant_growth_index.shtml). USGS's Earth Resources Observations Systems (EROS) recently developed a new protocol to remove the influence of water vapor, which interferes with one of AVHRR's measurement channels, artificially depressing many NDVI values (Heinz Center, 2003). For the Heinz Center's 2003 update, EROS reprocessed all raw data following this new protocol. EROS based this protocol on several sources, described and cited at http://edc.usgs.gov/greenness/whatnew.html.

(2) To determine the temporal bounds of the growing season, USGS calculated a moving average around each NDVI data point. A strong positive deviation from the moving average signaled the start of the growing season. Conversely, a lower-than-expected data signaled the end of the growing season. USGS describes this methodology in moderate detail online (http://edc2.usgs.gov/phenological/methods.html#methodsTS). While USGS lists no specific supporting references, it may be possible to learn more about growth season determination from some of the general NDVI references listed at http://edc.usgs.gov/greenness/refs.html.

(3) For a given year, all 2-week NDVI composites from the growing season were added together, generating a single "accumulated NDVI" value for the year. USGS does not mention this step online, but the Heinz report suggests that it obtained its data from USGS in this accumulated form. The Heinz Center (2003) notes that a detailed explanation of calculating growing-season

accumulated NDVI can be found in: B.C. Reed and L. Yang. 1997. Seasonal vegetation characteristics of the United States. Geocarto International 12(2):65–7.

(4) USGS sorted data by land cover type (forest, shrub/grassland, and cropland) in accordance with the National Land Cover Dataset (NLCD). In the NLCD system, each "pixel" of land (about 100 feet on a side) is assigned to one of 21 land-use categories, based on information from Landsat imagery and various US government agencies. USGS provides documentation for the NLCD system at http://landcover.usgs.gov/.

(5) The final presentation of this indicator compares annual NDVI values with an average of all 13 years for which data are available (1989-1993; 1995-2002). The Heinz Center obtained data from USGS in the form of NDVI data for each land cover type within each county. To derive a national NDVI figure for each land cover type, the Heinz Center averaged all county figures, weighted by land area. For each land cover type, the Heinz Center also calculated the average of all 13 years of annual NDVI data, creating a long-term mean for comparison. For this indicator, the long-term average is assigned a value of 1. If one year shows an NDVI value of 1.5 on this index scale, it means that particular year's NDVI was 1.5 times the 13-year average.

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

Since changes in plant growth can be indicative of several different environmental stressors (e.g., soil moisture, carbon dioxide levels, nitrogen deposition, ground-level ozone, climate change), it seems appropriate that a proxy for plant growth be considered when assessing functional trends in the nation s ecosystems. This sampling method is broad enough to cover national trends, while detailed enough to allow data to be broken down by region or by specific land cover type if desired. Data were collected by high-resolution equipment aboard a satellite, covering the entire surface of the lower 48 states down to 1 km squares. Broken down by land type and/or region, this indicator may also shed light on particular areas of concern e.g., a noticeable decline in farmland productivity that might indicate a problem with farm management or topsoil loss. The Heinz Center (2003) reports that NDVI data correlate well with other measures of plant growth, such as net carbon uptake and plant biomass production (http://www.heinzctr.org/ecosystems/national_technotes/natl_plant_growth_index.shtml). In addition, results for this indicator suggest some broad trends that are consistent across many regions and land cover types (e.g., high growth in 1993, low growth in 1996), although the Heinz Center could not explain what caused these patterns to occur. Still, sample design poses a few obstacles to fully answering the question this indicator was intended to answer (see also T4Q3 and T4Q4). Neither USGS nor the Heinz Center discusses the degree to which light absorption by plants may vary throughout the course of a day, and thus neither source provides explicit assurance that twice-daily measurements are sufficient to capture the full range of plants light absorption patterns within the overall indicator. The Heinz Center and USGS also do not discuss whether measurement time-of-day stayed consistent enough to allow for meaningful comparisons, although USGS/EROS scientists have indicated that they believe it was sufficiently consistent. In particular, the Heinz Center notes that one satellite drifted to a significantly later overpass time in 2000 (see T4Q4), but USGS/EROS scientists concluded that it was not a significant source of potential error (Heinz, 2003: http://www.heinzctr.org/ecosystems/national_technotes/natl_plant_growth_index.shtml; Carolyn Gacke, USGS, personal communication, 2005).

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

USGS designed this sample to generate a broad national index, so it is not targeted at any one sensitive population or ecosystem. However, because the indicator does allow data to be broken down by both region and vegetation type, it may be possible to track changes within a particular region or land use category of concern.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

No benchmark values of NDVI or terrestrial plant growth index are available to support any kind of unambiguous quantification of the state of the environment. The Heinz Center averaged 13 years of data to establish a baseline for comparison, but as these data all come from 1989 or later, this baseline should not necessarily be assumed to reflect the natural state of plant growth.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

USGS provides complete documentation of the AVHRR technology used to collect the raw data for this indicator (basic information at http://edcdaac.usgs.gov/1KM/avhrr_sensor.asp; Polar Orbiter Data User s Guide at http://www2.ncdc.noaa.gov/docs/podug/; similar information at http://edc.usgs.gov/guides/avhrr.html and http://edc.usgs.gov/greenness/tables.html). In addition, both the Heinz Center and USGS discuss the resolution and frequency of data collection for this indicator (http://www.heinzctr.org/ecosystems/national_technotes/natl_plant_growth_index.shtml; http://edc2.usgs.gov/phenological/methods.html#methodsTS). Several sources document the analytical procedures employed in the creation of this indicator. USGS s EROS website discusses the basic process of adding and subtracting data from two satellite channels in order to arrive at an NDVI figure for each data point (http://edc.usgs.gov/greenness/whatndvi.html). USGS also provides a brief online discussion of the process of smoothing the raw data into bi-weekly NDVI values (http://edc2.usgs.gov/phenological/methods.html#methodsTS); greater detail can be found in: Swets, D.L., B.C. Reed, J.R. Rowland, S.E. Marko, 1999. A weighted least-squares approach to temporal smoothing of NDVI. In 1999 ASPRS Annual Conference, From Image to Information, Portland, Oregon, May 17-21, 1999, Proceedings: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, CD-ROM, 1 disc. USGS lists several related references at http://edc2.usgs.gov/phenological/overview.html#references and http://edc.usgs.gov/greenness/refs.html. USGS describes the process of determining growing season bounds at http://edc2.usgs.gov/phenological/methods.html#methodsTS. For each growing season, USGS adds NDVI data to arrive at a single accumulated value for the year; this process is detailed in: B.C. Reed and L. Yang. 1997. Seasonal vegetation characteristics of the United States. Geocarto International 12(2):65 71. USGS separates data by land cover type using the National Land Cover Dataset (NLCD), a general description of which appears at http://landcover.usgs.gov. According to the Heinz Center (personal communication 2004), the creation of the NDVI index requires an area-weighted averaging approach because USGS reports annual accumulated NDVI by county, not by individual pixel. For the index, the long-term (13-year) mean receives a value of 1.0 and annual figures are depicted based on percent deviation from this mean. USGS does not directly document the procedure by which the full data set was recently recalculated to correct for the influence of water vapor (these new data appear in the Heinz Report s 2003 update). However, USGS does provide several references for this procedure at http://edc.usgs.gov/greenness/whatnew.html.

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

Raw satellite data are not available online. However, USGS does provide access to the full set of NDVI data, which has already been smoothed and compiled (http://edc.usgs.gov/products/landcover/ndvi.html). This data set includes bi-weekly NDVI, total growing season NDVI, growing season start and end data, and start-of-season NDVI. The Heinz Center specifically reports that data obtained from USGS were already sorted by county and by land cover type within each county. The Heinz Center has published numerical data corresponding with the graphs in the 2002 Heinz Report: http://www.heinzctr.org/ecosystems/national/datasets/plant_growth_by_ecosystem.shtml; http://www.heinzctr.org/ecosystems/national/datasets/plant_growth_west.shtml; http://www.heinzctr.org/ecosystems/national/datasets/plant_growth_east.shtml Basic NLCD data are available at http://landcover.usgs.gov/. While several additional sources of land cover data exist (e.g., USDA Forest Service; see list at http://www.heinzctr.org/ecosystems/national_technotes/natl_extent.shtml), USGS only used NLCD data for this indicator.

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

Reliance on historical measurements poses a limitation to the complete reproducibility of this study. However, USGS has already re-analyzed all of its original NDVI data, after recently developing a protocol to account for the distorting effect of water vapor in the atmosphere. This re-analysis exposes the possibility of reproducing the analytical portion of this study, provided that the raw data and specific algorithms can be obtained from USGS.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

NOAA has published a Polar Orbiter Data User s Guide that includes a section on the calibration of AVHRR Data: http://www2.ncdc.noaa.gov/docs/podug/html/c3/sec3-3.htm. USGS has not published quality control/quality assurance procedures specifically related to its NDVI data.

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

This indicator does not require any spatial extrapolation, as NOAA s satellites can gather data from the entire land area of the lower 48 states at least twice daily. Although measurements cannot be taken through cloud cover, USGS smoothes the twice-daily data over 2-week periods in order to minimize cloud effects, ensuring that the overall indicator represents all data locations. This indicator does employ a great deal of spatial generalization as it combines 1-km pixels and county-level NDVI values into a single national index for each land cover type. USGS and the Heinz Center have generalized appropriately, using an area-weighted approach to ensure that national NDVI reflects each county's NDVI proportional to land area (for each NLCD type). Because measurements are taken every day of the year, this indicator requires no temporal extrapolation. However, the analytical process does require some degree of temporal generalization in order to reduce the influence of various extraneous factors that can distort satellite measurements. This "smoothing" takes place following regression and weighting procedures that are accepted by USGS and documented in: Swets, D.L., B.C. Reed, J.R. Rowland, S.E. Marko, 1999. A weighted least-squares approach to temporal smoothing of NDVI. In 1999 ASPRS Annual Conference, From Image to Information, Portland, Oregon, May 17-21, 1999, Proceedings: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, CD-ROM, 1 disc. In addition, the data collection system requires that overall results be generalized from two measurements per day. Neither the Heinz Center (2003) nor USGS explicitly discusses whether this level of generalization is appropriate to capture the full range of variation in plant behavior over the course of a given day.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

Neither the Heinz Center nor USGS has published uncertainty estimates for the raw satellite data or the smoothed NDVI data. USGS has published uncertainty measurements for the National Land Cover Dataset (NLCD). According to basic information from the Heinz Center, the NLCD has 80% or higher accuracy for the eastern United States, while the western United States is still under review. A detailed discussion of error in the NLCD can be found at http://landcover.usgs.gov/accuracy.

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

The AVHRR represents a precise measuring technology, presumably with low uncertainty. However, without explicit uncertainty measurements for the raw data set, it is not possible to quantify any uncertainty that may exist. The data include some natural variability, but it does not negatively impact the utility of this indicator. While cloud cover and other factors can variability, USGS has designed the smoothing process to weed out these influences as much as possible. USGS also uses a specific protocol to handle the establishment of growing season boundaries another source of variability that is at least somewhat minimized through the use of statistical smoothing.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

(1) Geographic limitations. USGS did not analyze data for either Alaska or Hawaii, so this indicator cannot give any information about some of the unique ecosystem health issues that may be pertinent to Alaska or Hawaii. Particularly in the case of Alaska, where temperature has recently warmed faster than the global average and the treeline appears to be moving north as the permafrost melts (Lloyd and Fastie, 2003), plant growth index might reveal interesting trends. Lloyd, A.H., Fastie, C.L. 2003. Recent changes in treeline forest distribution and structure in interior Alaska. Ecoscience 10(2). (2) Absence of baseline data. Data are available from USGS beginning in 1989, with one year (1994) missing from the sampling period. Without more data, it is hard to tell whether trends are related to natural variability, natural climate oscillations, or long-term changes that should raise concerns. (3) Effects, not causes. While this indicator might identify trends, it does not identify specific underlying causes. In this sense it is essentially a holistic measure of how well plants are growing. Even if it can be determined that a particular trend in NDVI is attributable to long-term changes rather than natural variability or climate oscillation, it may not be easy to determine the actual mechanism of that change. (4) The Heinz Center notes that one satellite drifted to a new overpass time in 2000, causing NDVI to be

measured in late afternoon rather than at the normal measuring time closer to midday. While USGS (EROS) does not fully discuss the potential effects of this drift on NDVI measurements, EROS scientists have concluded that in their judgment, the 2000 orbital drift was not such a significant source of potential error that it would require correction (Carolyn Gacke, USGS, personal communication, 2005; Heinz, 2003: http://www.heinzctr.org/ecosystems/national_technotes/natl_plant_growth_index.shtml). Nonetheless, sources like Nemani et al. (2003) discuss ways to correct NDVI data for satellite drift, should correction be necessary. Technical Supplement for: Nemani, R.R., C.D. Keeling, H. Hashimoto, W.M. Jolly, S.C. Piper, C.J. Tucker, R.B. Myneni and S.W. Running. 2003. Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. Science 300 (June 6, 2003). Technical Supplement located at http://www.ntsg.umt.edu/tops/document/nemani-et-al-supplement.pdf.